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THE MIDDLE PALEOZOIC STRATIGRAPHY OF THE CENTRAL ROCKY MOUNTAIN REGION

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PART III

STRATIGRAPHY—*continued*

THE SILURIAN SYSTEM

In Utah.—This system, not including the Richmond series, is not known with certainty in the central Rocky Mountain region, except in northern Utah, where it was included by Weeks[1] under the name "Paradise limestone," which has been supplanted in official usage by the "Laketown dolomite" of Richardson.[2] Its fauna does not comprise many species, but is ample to demonstrate that the system is Silurian.[3] It is closely allied to the Niagaran faunas of other regions.

In Nevada.—This system may be represented in the upper part of the Lone Mountain limestone of western Nevada, although no diagnostic Silurian fossils have been reported from that formation. The following is an extract from Iddings' section near Modoc Peak, in the Eureka district:

3. Shaly limestone, rich in fossils. Lower part of Nevada limestone.
2. 550 feet. Light-gray siliceous limestone, with fine lines of bedding; in upper portion weathering in almost rectangular fragments; growing less siliceous toward the bottom.
1. 140 feet. Light-gray, highly crystalline, saccharoidal dolomite; not siliceous.[4]

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[1] F. B. Weeks, unpublished manuscript, *U.S. Geol. Survey.*

[2] G. B. Richardson, "The Paleozoic Section in Northern Utah," *Amer. Jour. Sci.*, 4th Ser., XXXVI (1913), 406–15.

[3] Cf. E. M. Kindle, "Occurrence of Silurian Faunas in Western America," *Am. Jour. Sci.*, 4th Ser., XXV (1908), 125 ff.

[4] Arnold Hague, *op. cit.*, p. 66. Section measured by J. P. Iddings.

These descriptions show a marked resemblance to the section at Blacksmith Fork, from the lower part of the Jefferson down into the Laketown dolomite.

On the south slope of Quartz Peak in the Pahranagat Range in southern Nevada, about 140 miles south of Eureka, the Lone Mountain includes the following member:

2. 335 feet. Massive bedded dark siliceous limestone, with a stratum (not far above the base) 30 feet thick, almost made up of a species of *Pentamerus*.[1]

This, again, is strikingly like the Laketown.

Is the Laketown dolomite in part Devonian?—The uppermost member of the Laketown dolomite in the Blacksmith Fork section, 202 feet thick, is of much the same type as the Leigh formation of northwestern Wyoming. It immediately underlies beds of typical Jefferson dolomite. In the Teton River section the basal member (23 feet thick) of Blackwelder's[2] Darby (Jefferson) formation is of similar character, and is separated by an erosion surface from the underlying Leigh formation. In the Livingston Peak section there is a member, 21 feet in thickness, which is identical in type with the true Leigh, but which lies above the cliff-making Upper Bighorn dolomite, at the base of the Jefferson dolomite. In the Crandall Creek section the corresponding member, 26 feet thick, overlies a 47-foot sequence of variegated beds which lie disconformably upon the Upper Bighorn. At Livingston Peak and at Teton River, ostracods like those which are characteristic of the Leigh formation were found in this repetition of the Leigh type at the base of the Devonian system.

In brief, the uppermost member of the Laketown dolomite in northern Utah corresponds in lithologic character, and in relation to the overlying Jefferson dolomite, to the member which farther north appears to have been the introductory deposit of the first Devonian submergence. This relation suggests that the Utah member in question belongs with the Devonian rather than with the Silurian system. This interpretation has been followed in the correlation tables and diagrams accompanying this thesis, where the beds just discussed appear as Member 2 of the Devonian system.

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[1] Arnold Hague, *op. cit.*, p. 196.

[2] Eliot Blackwelder, unpublished manuscript, *U.S. Geol. Survey.*

Their much greater thickness in Utah may mean that the Devonian submergence proceeded slowly northeastward from that region, or that deposition was more rapid there.

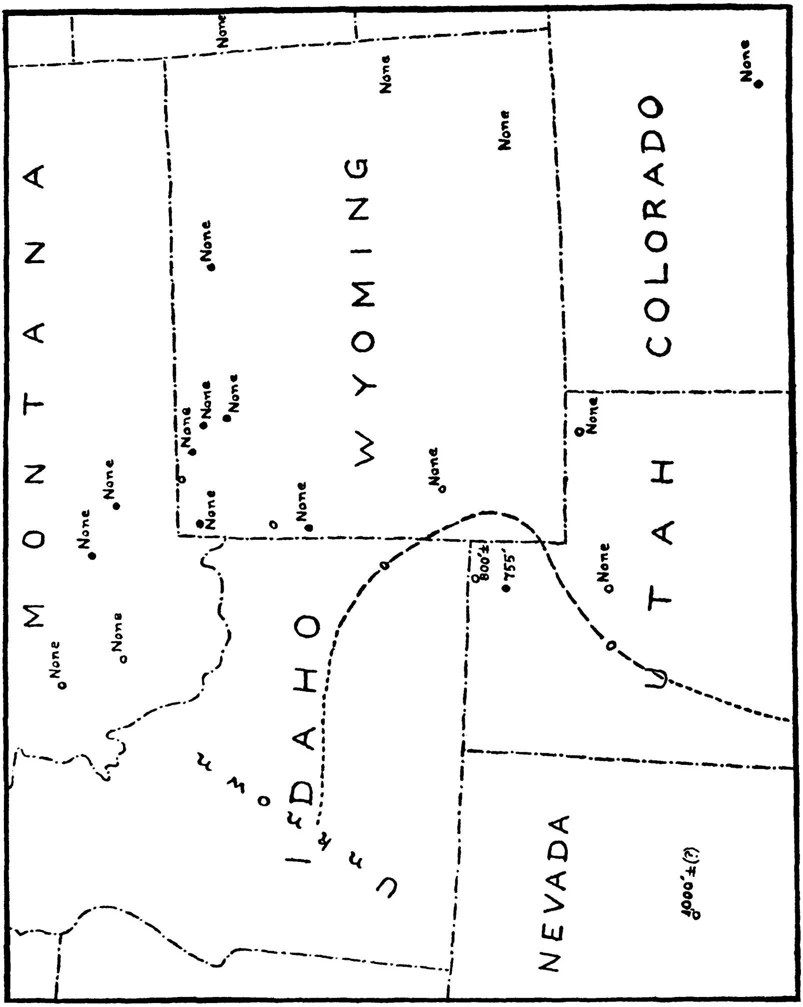

FIG. 9—Map showing the extent and thickness of the Silurian system

Pre-Laketown and pre-Devonian emergence.—The base of the Laketown dolomite at Blacksmith Fork is clearly disconformable upon the Fish Haven formation. No evidence of a break between Silurian and Devonian has been noted in that section; and Kindle, chiefly because of the persistance of *Halysites catenulatus* into the Jefferson dolomite, favors the idea of continuous sedimentation in this locality from Silurian into Devonian. Elsewhere in the Rocky Mountains, however, where the Silurian is absent, there was certainly an emergent interval immediately preceding the inauguration of Devonian sedimentation. The fact that no physical evidence of hiatus at that time has been noted as yet in northern Utah means little. The recurrence of *Halysites* in the Devonian certainly means no more, as regards continuity of submergence, than its persistence from the Richmond into the Silurian; yet the disconformity between the Richmond and the Silurian on Blacksmith Fork is well marked.

How far the Silurian system originally extended over the Rocky Mountain province can only be conjectured. Throughout Wyoming, wherever the Devonian occurs, it is apparent that the Silurian system, if ever represented, was completely removed by erosion prior to the Devonian submergence.

A small fauna collected by Blackwelder in the Gros Ventre Range from beds just below the Leigh dolomite was referred by Kindle and Weller to the Silurian, and by Ulrich to the Richmond.[1] The latter interpretation is probably correct, as the Leigh of the Teton Range is confidently correlated with part of the Richmond series in the Bighorn Range. Blackwelder's section in the Gros Ventres does not include beds of the types which characterize the Laketown dolomite in Utah.

The Silurian is not represented in Hintze's[2] section in the central Wasatch. The beginning of known Devonian deposition in that region was certainly preceded by an interval of emergence. Neither Silurian nor Devonian strata are known in the Uinta Range.[3]

THE DEVONIAN SYSTEM: THE JEFFERSON DOLOMITE

The basal division of the Jefferson dolomite.—The age of the beds here called Members 1 and 2 of the Devonian system has been discussed under the Silurian. Member 3, which follows 2 in apparent conformity wherever both are present, was the earliest development of the most characteristic Jefferson type of dolomite —dark-brown in color, saccharoidal, and giving forth a strong bituminous odor when freshly broken. The data suggesting disconformity at the top of Member 3 are summarized in the discussion of disconformities (pp. 131–34).

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[1] Eliot Blackwelder, "Origin of the Bighorn Dolomite of Wyoming," *Bull. Geol. Soc. Amer.*, XXIV (1913), 610.

[2] *Op. cit.*

[3] F. B. Weeks, *op. cit.*, XVIII (1907), 427–48.

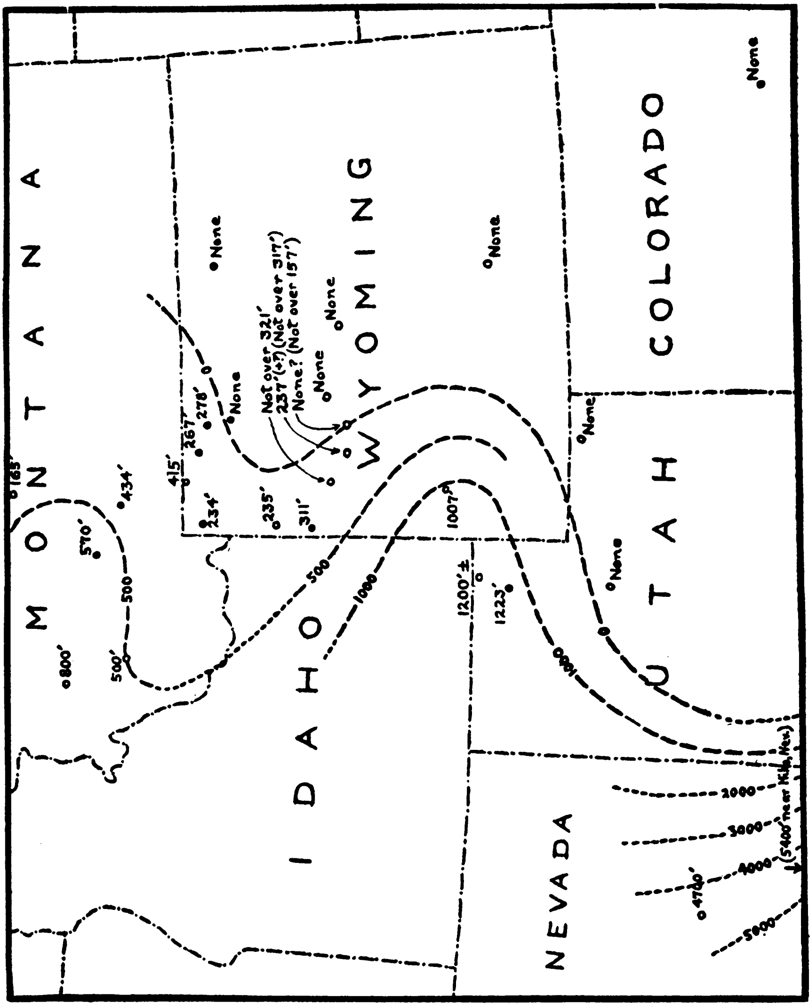

FIG. 10.—Map showing the extent and thickness of the Jefferson dolomite (Lower [?] and Middle Devonian) and correlated formations.

The main division of the Jefferson dolomite is dominated by a rather uniform succession of fairly massive, fetid, dark-brown dolomites, but includes toward its base a minor variegated sequence of thin members (4 to 8, inclusive), among which are light-colored dolomite, and locally (Labarge Mountain, Blacksmith Fork) sandstone. The correlation of these minor members on a lithologic basis has been attempted, but cannot be considered very reliable. In no two localities is there the same succession of members throughout the formation, although there is a notable degree of correspondence between the Crandall Creek and Teton River sections, for example. In the Dead Indian Creek, Livingston Peak, Logan, Labarge Mountain, and Blacksmith Fork sections the variegated members are relatively ill-developed, and the outstanding feature of the formation is a nearly uniform sequence, 200 feet thick or more, of what has been described above as the most characteristic Jefferson type of dolomites.

Members 12 to 14 of the Devonian system, above the main body of the Jefferson dolomite, are differentiated only at Blacksmith Fork and at Labarge Mountain, where they have a combined thickness exceeding 200 feet. They appear not to be represented in the sections in northwestern Wyoming and southern Montana. This fact, with certain other evidence, is strongly suggestive of an emergent interval between Members 14 and 15. (See discussion of disconformities, p. 132.)

The upper division of the Jefferson dolomite.—Member 18 is distributed with remarkable uniformity over a very wide area, and has been distinguished in nearly every locality within the scope of this thesis where the Jefferson dolomite has been described in any detail. Its brecciated structure, together with an abundance of calcite geodes in some places, give its weathered surfaces a characteristic nodular, pitted appearance. It is everywhere separated from the main mass of the Jefferson by a sequence of thin-bedded, largely platy dolomites. At Labarge Mountain the base of this sequence is marked by 10 feet of sandstone (Member 15); and in the Teton River section its lower portion contains some thin beds of sandstone, and quartz grains are scattered through several of the beds of dolomite.

This upper division of the Jefferson, as indicated by the correlation diagrams, maintains a fairly constant development even where the main body of the formation beneath it shows much variability.

The beds doubtfully referred to Member 18 in the Goose Creek Ridge and Rattlesnake Mountain sections are not typical of that member, but resemble it in being massive and in underlying a series of thin-bedded dolomites which possess all the essential characters of Member 19. (See discussion of the Three Forks formation, pp. 383–84.) It is perhaps more likely that the beds in question really belong to the Richmond series.

Misuse of the name "Jefferson" in Yellowstone Park and vicinity.—The name "Jefferson" was first used by Peale[1] to describe the dark limestones overlying the Gallatin formation in the Three Forks quadrangle, Montana. The strata included by Peale under that name are now believed to be entirely of Devonian age.[2] As they comprise everything between the Gallatin formation below and the Three Forks shale above in the type locality of the formation, it was natural for other geologists to apply the name "Jefferson" to all the strata between those two formations in neighboring areas. In the Livingston quadrangle,[3] Montana, and in the Absaroka[4] quadrangles, Wyoming, however, Hague confined the name "Jefferson" to the strata which he regarded as Silurian, and extended the name "Three Forks" to include all the limestones carrying Devonian fossils. Iddings and Weed, in Yellowstone Park,[5] employed the names in similar fashion, but not altogether consistently in different parts of the Park.

With the aid of his own field notes, and by as careful a correlation of members as the published descriptions permit, the writer has prepared the accompanying tentative correlation table (Fig. 11) of the sections measured by Iddings and Weed, adding three of his own sections for comparison. The "Jefferson" of Hague, Iddings, and Weed is seen to include the Bighorn dolomite as its chief constituent, and their "Three Forks limestone" consists chiefly of beds which are properly to be correlated with part of the true Jefferson dolomite as originally defined by Peale. The Devonian fossils identified by Girty[1] from Yellowstone Park came from beds

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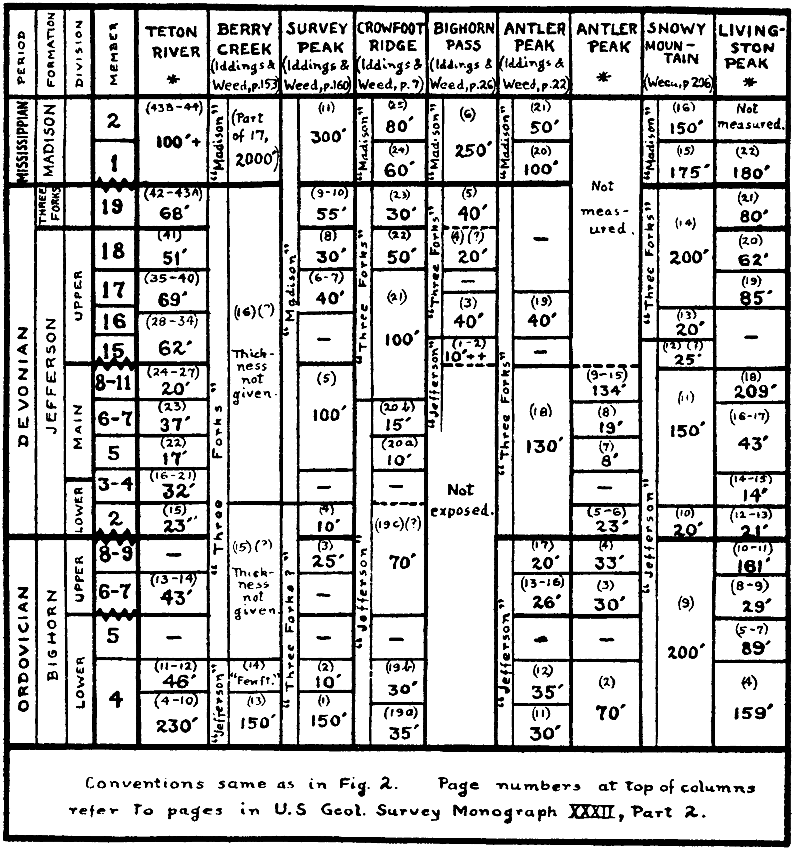
[1] A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U.S. Geol. Survey, Bull. 110* (1895).

[2] E. M. Kindle, letter of March 29, 1916; Edwin Kirk, letter of June 13, 1915.

[3] Arnold Hague, "Description of the Livingston Sheet," *Geol. Atlas U.S.*, Folio 1 (1894).

[4] Arnold Hague, "Description of the Absaroka Quadrangle," *Geol. Atlas U.S.*, Folio 52 (1899).

[5] J. P. Iddings and W. H. Weed, "Descriptive Geology of the Gallatin Mountains," *U.S. Geol. Survey, Monographs*, XXXII, Part 2 (1899), chap. i; "Descriptive Geology of the Northern End of the Teton Range," *ibid.*, chap. iv; W. H. Weed, "Geology of the Southern End of the Snowy Range," *ibid.*, chap. vi.



PERIOD	FORMATION	DIVISION	MEMBER	TETON RIVER *	BERRY CREEK (Iddings & Weed, p.153)		SURVEY PEAK (Iddings & Weed, p.160)		CROWFOOT RIDGE (Iddings & Weed, p. 7)		BIGHORN PASS (Iddings & Weed, p.26)		ANTLER PEAK (Iddings & Weed, p.22)		ANTLER PEAK *	SNOWY MOUNTAIN (Weed, p 206)		LIVINGSTON PEAK *
MISSISSIPPIAN	MADISON		2	(43B-44) 100'+	"Madison"	(Part of 17, 2000')	"Madison"	(11) 300'	"Madison"	(25) 80'	"Madison"	(6) 250'	"Madison"	(21) 50'	Not measured.	"Madison"	(16) 150'	Not measured.
			1							(24) 60'				(20) 100'			(15) 175'	(22) 180'
DEVONIAN	THREE FORKS		19	(42-43A) 68'	"Three Forks"	(16)(?) Thickness not given.		(9-10) 55'	"Three Forks"	(23) 30'	"Three Forks"	(5) 40'	"Three Forks"	—		"Three Forks"	(14) 200'	(21) 80'
	JEFFERSON	UPPER	18	(41) 51'				(8) 30'		(22) 50'		(4)(?) 20'						(20) 62'
			17	(35-40) 69'				(6-7) 40'		(21) 100'		—						(19) 85'
			16	(28-34) 62'				—				(3) 40'		(19) 40'			(13) 20'	—
			15								"Jefferson"	(1-2) 10'++		—		"Jefferson"	(12)(?) 25'	
		MAIN	8-11	(24-27) 20'				(5) 100'	"Jefferson"			Not exposed.		(18) 130'	(9-15) 134'		(11) 150'	(18) 209'
			6-7	(23) 37'						(20b) 15'					(8) 19'			(16-17) 43'
			5	(22) 17'						(20a) 10'					(7) 8'			
		LOWER	3-4	(16-21) 32'				—		—					—			(14-15) 14'
			2	(15) 23'		(15)(?) Thickness not given.	"Three Forks ?"	(4) 10'		(19c)(?) 70'					(5-6) 23'		(10) 20'	(12-13) 21'
ORDOVICIAN	BIGHORN	UPPER	8-9	—				(3) 25'					"Jefferson"	(17) 20'	(4) 33'		(9) 200'	(10-11) 161'
			6-7	(13-14) 43'				—						(13-16) 26'	(3) 30'			(8-9) 29'
		LOWER	5	—				—		—				—	—			(5-7) 89'
			4	(11-12) 46'	"Jefferson"	(14) "Few ft."		(2) 10'		(19b) 30'				(12) 35'	(2) 70'			(4) 159'
				(4-10) 230'		(13) 150'		(1) 150'		(19a) 35'				(11) 30'				

Conventions same as in Fig. 2. Page numbers at top of columns refer to pages in U.S Geol. Survey Monograph XXXII, Part 2.

FIG. 11.—Tentative correlation table for sections in Yellowstone Park and vicinity

well down in the Jefferson formation, which explains their likeness to the Jefferson fauna known from other regions.[1] The variability of the Three Forks formation from shale to limestone along the strike has been overestimated because of this same erroneous correlation.

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[1] G. R. Girty, "Devonian and Carboniferous Fossils of the Yellowstone National Park," *U.S. Geol. Survey, Monographs*, XXXII, Part 2 (1899), chap. xii.

Correlation of the Jefferson dolomite with the Nevada limestone.—The Jefferson dolomite, as known in Montana and northern Utah, has been correlated definitely by Kindle[2] with the Nevada limestone of eastern Nevada, on paleontological grounds. Of the eleven specifically identified forms described by Kindle from the Jefferson formation, other than new species, seven were described by Walcott[3] from the Nevada limestone. Of the 32 forms partially or completely identified by Kindle from the Jefferson Limestone, only three are of genera not described by Walcott from Nevada.

The total thickness of the Nevada limestone is estimated by Hague[4] at 6,000 feet. Although accuracy is not claimed for this figure, it cannot be doubted that the Nevada is very much thicker than any described section of the Jefferson limestone. The following figures are given by Hague for the thickness of the Nevada limestone at various localities in the Eureka district:

Newark Mountain[5] (Bed 5): 3,500 feet. Considered by Hague[6] to be less than (the upper) half of the total thickness of the formation. A small Upper Devonian fauna was collected "several hundred feet below the top."

Near Modoc Peak[7] (Beds 3–18): 4,710 feet. (Hague regarded the Nevada as including more than 700 feet of lower strata also.) Rich Lower Devonian fauna in lower 425 feet (Beds 3–4); no fossils other than "*Stromatopora*" and "*Chaetetes*" found at higher horizons.

East of Lamoureux Canyon[8] (Beds 1–5): 3,000 feet, top not exposed. Basal 200 feet carries a rich Lower Devonian fauna.

County Peak:[9] 4,500 feet. Fossils at three horizons.[10]

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[1] Cf. E. M. Kindle, "Fauna and Stratigraphy of the Jefferson Limestone in the Northern Rocky Mountain Region," *Bull. Amer. Pal.*, IV, No. 20 (1908), 22.

[2] *Ibid.*, pp. 20–21.

[3] C. D. Walcott, "Paleontology of the Eureka District," *U.S. Geol. Survey, Monographs*, VIII (1884).

[4] Arnold Hague, "Geology of the Eureka District, Nevada," *U.S. Geol. Survey, Monographs*, XX (1892), 13, 63–64.

[5] *Ibid.*, pp. 82, 158.

[6] *Ibid.*, p. 158.

[7] *Ibid.*, p. 66.

[8] *Ibid.*, p. 67.

[9] *Ibid.*, p. 68.

[10] *Ibid.*, pp. 78–80.

The occurrence of such great thicknesses at four distinct localities renders it unlikely that the true thickness has been greatly overestimated because of duplication by faulting.

The two chief fossiliferous horizons in the Nevada limestone are near the base and near the top, and are separated by from 2,000 to 4,000 or more feet of strata which have yielded no diagnostic fossils. The fauna described by Kindle from the Jefferson limestone includes 10 forms[1] (2 of which are specifically identified) which occur only in the lower part of the Nevada limestone, 4[2] (3 of which are specifically identified) which occur in both the upper and the lower horizons, and 5[3] (2 of which are specifically identified) which occur in the upper part of the Nevada only. Although this evidence is meager, it suggests that the Jefferson limestone includes representatives of both the basal and upper parts of the Nevada limestone. It is possible that the disconformity between Members 14 and 15 of the Jefferson, for which evidence is cited on page —, represents a large part of the barren middle portion of the Nevada. This would mean that the greater thickness of the Nevada, as compared with the Jefferson, was due, at least in part, to the presence in the Nevada of members which either never were deposited in the Rocky Mountain province or were eroded from that region in Devonian time; that during the Devonian period the eastern part of the Great Basin was more persistently submerged or less elevated in emergent intervals (or both) than was the central Rocky Mountain Region.

In the Pahranagat Range, west of Hiko, in southeastern Nevada, Walcott[4] measured a section including 5,400 feet of strata which he assigned to the Devonian. From this sequence he obtained 22 fossil forms, to 9 of which he assigned definite specific names. All of these forms are identical, according to Walcott's lists, with species found in the Nevada limestone in the vicinity of Eureka—some in the lower, some in the upper, fossiliferous horizon there.

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[1] *Favosites* sp., *Chonetes* cf. *macrostriata*, *Stropheodonta* sp., *Schuchertella chemungensis*, *Athyris* sp., *Platyceras* sp., *Actinopteria* sp., *Loxonema approximatum?*, *Loxonema nobile*, *Bythocypris?* (*Leperditia?*) sp.

[2] *Stromatopora* sp., *Productella* cf. *spinulicosta* (*Productus subaculeatus*), *Atrypa reticularis*, *Martinia maia*.

[3] *Spirifer utahensis* Meek (*S. disjunctus* Sowerby), *S. engelmanni* Meek, *Pterinopecten* sp., *Naticopsis* sp., *Pleurotomaria* sp.

[4] Arnold Hague, *op. cit. ult.*, pp. 197–99.

THE DEVONIAN SYSTEM: THE THREE FORKS FORMATION

Type sections.—As defined by Peale[1] in the type sections in the Three Forks quadrangle, Montana, this formation includes all strata between the top of Member 18 of the Jefferson dolomite and the base of the Madison limestone (Mississippian). Raymond[2] has collected and studied large faunas from several horizons in the type locality opposite Logan. Haynes[3] has carried on Raymond's work, and studied in detail the stratigraphy of the formation in all exposures within about twenty miles of Logan.

Members 19 and 20.—The chief fossiliferous zone of the Three Forks, Member 20 of the Devonian system (Members 4 and 5 of Haynes) has not been identified in Montana east of the Three Forks quadrangle, nor anywhere in Wyoming. It is quite possible that outliers of it may yet be found in those areas, however, as Member 19 is widely distributed there. The top of the Jefferson dolomite is clearly marked in nearly every section in western Wyoming and southwestern Montana by the massive, brecciated Member 18. Were it not for this, the beds of Member 19 might easily be confused with those of Member 17, to which they bear much likeness. In the Dead Indian Creek section, where Member 18 was not recognized, certain strata were assigned to Member 19 because their relation to overlying strata corresponds to the relation of Member 19 to overlying beds in the Crandall Creek section, where Member 18 is present.

Beds of doubtful age in the Bighorn Range, and near Cody.—In the Goose Creek Ridge and Rattlesnake Mountain sections there is a belt of platy buff and yellow dolomites and calcareous shales between the top of the fossiliferous Bighorn and the base of the typical Madison, which corresponds closely in lithological character with Member 19 as developed farther northwest. In the Bighorn

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[1] A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U.S. Geol. Survey, Bull. 110* (1893).

[2] P. E. Raymond, "On the Occurrence in the Rocky Mountains of an Upper Devonian Fauna with *Clymenia*," *Amer. Jour. Sci.*, XXIII (1907), 116–22; "The Fauna of the Upper Devonian of Montana," *Annals of the Carnegie Museum*, V (1909), 141–58; "The *Clymenia* Fauna in the American Devonian," *Proc. Seventh Intern. Zoöl. Cong.* (Boston, 1907).

[3] W. P. Haynes, *op. cit.*, pp. 13–54.

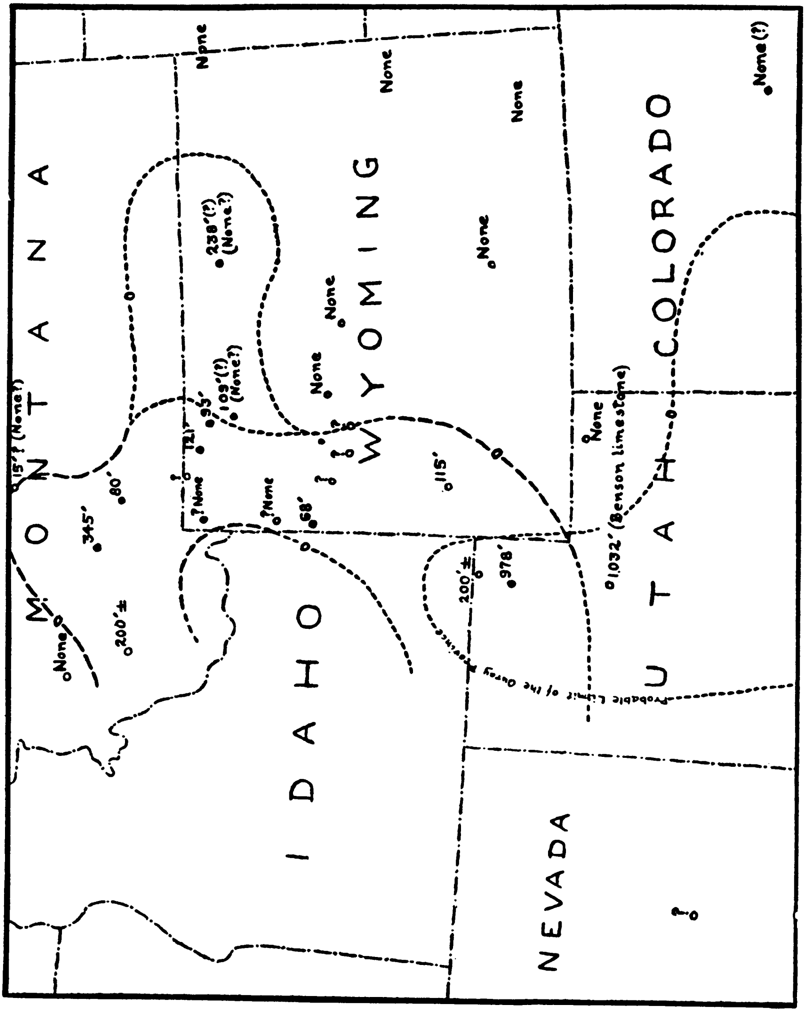

FIG. 12.—Map showing the extent and thickness of the Three Forks (Upper Devonian) and correlated formations.

Range, where this belt is 238 feet thick, it was considered by Darton[1] to be the basal member of the Madison limestone; but it is unlike any part of the true Madison seen by the writer elsewhere. So far as known, it is wholly barren, as is likewise Member 19. It may belong to the Richmond series. However, if the Devonian system is represented in the sections named, it includes this belt, and possibly the underlying massive member which separates it from the fossiliferous Upper Bighorn.

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[1] N. H. Darton, "Description of the Bald Mountain and Dayton Quadrangles," *Geol. Atlas U.S.*, Folio 141 (1906), p. 4; Goose Creek section.

Member 21, comprising black shales overlain by yellow or red aranaceous strata, is found at Crandall Creek and Dead Indian Creek in the Absaroka Range with a development almost precisely like that shown in most of Haynes's sections near Three Forks. Haynes[1] considers that the fauna of this member is transitional to the Mississippian.

The Three Forks formation in northern Utah; correlation with the Benson and Ouray limestones.—Richardson[2] reports very poor exposures of the Three Forks formation in the Randolph quadrangle in northern Utah, with red shaly limestone (Member 19?) as the most conspicuous element in the float. The fauna collected by him from this formation, and identified by Kindle, indicates a mingling of Ouray and Three Forks species. Five[3] of the 7 species in Richardson's list occur also in the Devonian fauna of the Ouray limestone in Colorado,[4] and 6[5] of the 7 occur in the Three Forks formation of the type area.

Haynes[6] has noted the probability of a correlation between the Three Forks and the lower (i.e., the Devonian) part of the Ouray. Of 25 species and varieties of brachiopods listed by Kindle[7] from the latter horizon, and of 27 listed by Haynes[8] from "Bed 5" (part of Member 20 of this paper) of the former, there are 11 which occur in both lists.

[1] *Op. cit.*, pp. 21, 28.

[2] *Op. cit.*, p. 412.

[3] *Camarotoechia* cf. *contracta*, *Productella coloradensis*, *Schizophoria striatula* var. *australis*, *Spirifer whitneyi* var. *animasensis*, and *Spirifer notabilis*.

[4] E. M. Kindle, "The Devonian Fauna of the Ouray Limestone," *U.S. Geol. Survey, Bull. 391* (1909).

[5] *C. contracta*, *P. coloradensis*, *S. striatula* var. *australis*, *S. whitneyi* var. *animasensis*, *Syringothyris* cf. *carteri*, *Cleiothyridina* sp.

[6] *Op. cit.*, p. 24.

[7] E. M. Kindle, "The Devonian Fauna of the Ouray Limestones," *U.S. Geol. Survey, Bull. 291* (1909), p. 12.

[8] *Op. cit.*, p. 25.

Richardson[1] estimates the thickness of the Three Forks formation in the Randolph area at 200 feet. In the Blacksmith Fork section both the upper and the lower limits of the Three Forks are marked by the usual sharp lithologic contrasts, yet the strata between the Jefferson and the Madison total 978 feet in thickness. For the most part, this sequence is composed of the usual Three Forks types; but between the green shales below and the black shales above there appears a 360-foot belt of blue-gray limestones (Member 20B).

Less than ten miles south of the above section, in the canyon east of Paradise P.O., Utah, Kindle[2] noted no representative of the Three Forks formation. In the region east of Ogden such a representative is probably to be found, as suggested by Richardson,[3] in the reddish shales and thin-bedded limestones mentioned by Blackwelder,[4] which are 250 feet thick on the South Fork of Ogden River.

In the South Fork of Big Cottonwood Canyon, about 75 miles south of Blacksmith Fork, occurs the Benson limestone of Hintze,[5] comprising 1,032 feet of blue limestone. From a horizon in the upper part of this formation Hintze collected a fauna which is very like that of the Ouray limestone. His description of the Benson indicates that it is lithologically very different from the typical Three Forks. The belt of blue-gray limestones in the middle of the Three Forks formation at Blacksmith Fork, and the upper division of the Jefferson dolomite in the same section, correspond roughly in character with the Benson. This fact, together with the mingled Ouray–Three Forks fauna found in the Randolph quadrangle, suggests the possibility that the Ouray lithologic type dovetails into the Upper Devonian rocks of the more northern and western province.

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[1] G. B. Richardson, *op. cit.*, p. 412.

[2] E. M. Kindle, "The Fauna and Stratigraphy of the Jefferson Limestone in the Northern Rocky Mountain Region," *Bull. Amer. Pal.*, IV, No. 20 (1908), 16.

[3] *Op. cit.*, p. 412. Also Eliot Blackwelder, letter of April 29. 1915.

[4] Eliot Blackwelder, "New light on the Geology of the Wasatch Mountains, Utah," *Bull. Geol. Soc. Amer.*, XXI (1910), 528–29.

[5] F. F. Hintze, Jr., *op. cit.*, pp. 88–142.

SUMMARY OF RESULTS ON SPECIAL PROBLEMS OF INVESTIGATION

The following progress has been made toward the solution of the four special problems noted in the foreword of this thesis:

1. *The Age of the "Jefferson dolomite" in the Livingston, Yellowstone National Park, and Absaroka quadrangles.*—It has been shown beyond doubt that the Ordovician Bighorn dolomite is present, and characteristically developed, throughout the Absaroka Range, as far north as Livingston Peak in Montana, and in Yellowstone Park. It was included in the "Jefferson dolomite" of Hague, Iddings, and Weed. It is followed disconformably by the true Jefferson dolomite (Devonian), much of which was erroneously included by earlier writers under the name "Three Forks formation."

2. *Middle Paleozoic disconformities.*—A well-marked disconformity between the Lower (Trenton) and Upper (Richmond) divisions of the Bighorn dolomite has been discovered in the Absaroka Range. In northwestern Wyoming and southwestern Montana the existence of disconformities at the base of the Bighorn dolomite and at the base of the Jefferson dolomite has been established. Much evidence has been gathered which points toward the existence of disconformities at at least one horizon within the Jefferson dolomite, and at the base of the Mississippian system.

3. *Correlation of Upper Cambrian and Ordovician formations in Wyoming with those in Utah.*—The Upper and Lower divisions of the Fish Haven dolomite in northern Utah have been shown to correspond in lithologic character to the Upper and Lower divisions, respectively, of the Bighorn dolomite; and there is evidence of a disconformity between the two divisions of the Fish Haven dolomite, as well as between those of the Bighorn. Several members of the Gallatin formation of Wyoming and Montana have been tentatively correlated on lithologic grounds with members of the St. Charles formation (Upper Cambrian) in northern Utah, and the main flat-pebble conglomerate zone at the top of the Gallatin is tentatively correlated with a member of similar character in Utah which includes the top of the St. Charles formation and the lower part of the Garden City (Beekmantown) formation.

4. *Relation of Ordovician to Silurian in Utah.*—In the vicinity of Blacksmith Fork, northern Utah, the Laketown dolomite (Silurian) has been found to be separated from the underlying Upper Fish Haven dolomite (Richmond) by a well-marked disconformity.

HISTORICAL SKETCH

UPPER CAMBRIAN AND LOWER ORDOVICIAN

Extent of submergence.—The present extent and variations in thickness of the sediments deposited in the central Rocky Mountain region during the Upper Cambrian-Lower Ordovician submergence are shown in Fig. 7. It will be noted that this is not a paleogeographic map in the usual sense, as no attempt has been made to indicate the original extent of these sediments, other than to show them as continuous across relatively small areas, from which they have certainly been removed by post-Cretaceous erosion.

The much greater thickness of this group of sediments in western and northern Utah and in Nevada, as compared with Wyoming and Montana, means either that (1) sedimentation continued longer or (2) took place more rapidly in the first-named region, or that (3) during the succeeding interval of emergence erosion removed a larger part of the series in question from Wyoming and Montana than from the adjoining region to the southwest. Certainly the first and last, and perhaps all three, of these factors combined to produce the net result. A logical supposition is that the sea retreated from northeast to southwest, so that deposition continued in the Great Basin after erosion had begun on recently emerged areas in Wyoming and Montana. The wide-spread uniformity in type of the sediments in question indicates a similarly extensive uniformity of conditions of deposition, and suggests that the second factor was not of great importance.

Paucity of clastic sediments.—The beginning of the Upper Cambrian transgression in Utah was marked by a deposit of sand of varying thickness. From that time until the close of the Beekmantown epoch no part of the region in which the St. Charles, Garden City, Gallatin, and Upper Deadwood formations are found received any notable quantity of arenaceous sediment, so far as the record now shows. During long intervals the deposits accumulating on the floor of the clear sea which covered this area were nearly or quite without clastic ingredients. At no time was clastic mud brought in in such quantity as greatly to preponderate over calcareous matter. This condition makes it certain that there were no high shores, nor debouchures of streams draining areas of high relief or dry climate, in or very near to the region under consideration.

Evidence that the sea was shallow.—The intraformational conglomerates which characterize the upper part of the Upper Cambrian and much of the Beekmantown series record the fact that the seas of that time were shallow enough to permit the breaking and movement, by waves or currents, of freshly or partly consolidated sediments on the sea bottom.

The Chazyan(?) sands.—Somewhat later in the Ordovician period, probably in the Chazyan epoch, a flood of sand swept over the extreme northern part of Utah and much of eastern Nevada (see Fig. 8). This was probably the result of an uplift of neighboring lands, perhaps in central or eastern Utah.

Emergence and peneplanation.—Subsequently, the entire region shown in the accompanying maps (Figs. 6–10, 12, 13) emerged and the freshly exposed sediments were subjected to extensive erosion, which continued until about the close of the Black River epoch. This emergence took place without any appreciable deformation of the Cambrian and early Ordovician sediments. Probably it produced no great relief in the region where those sediments are known. The first deposits of the succeeding submergence were laid down on a surface whose relief probably did not exceed 200 feet in all northern and western Wyoming, and on which, in that region, slopes as steep as 10° were, so far as known, nowhere more than a few feet or yards in length. Either the relief was not greater than this at any time during the interval of emergence or a rougher surface was reduced to this condition by stream erosion during that interval, with the aid of marine planation at the border of the advancing Middle Ordovician sea.

MIDDLE AND UPPER ORDOVICIAN

The Trenton submergence.—About the end of Black River time the sea readvanced into the central Rocky Mountain region, probably from the west. The area known to have been covered by this inundation in Utah and Wyoming is approximately the same as in the case of the Late Cambrian submergence (see Fig. 9). Locally, in Wyoming a little sand was deposited in depressions of the surface as the sea-border transgressed the region; but the main body of limestone which represents this Trenton submergence is wholly free from arenaceous and shaly matter. The seas were even more persistently clear than in Upper Cambrian time.

The masses of calcareous algæ which make up much of the Lower Bighorn and Lower Fish Haven dolomites bear witness to the prevalent shallowness of the water.

The post-Trenton emergence.—Sedimentation was interrupted by emergence between Trenton and Richmond times, but the erosion accomplished during this interval seems to have been slight. If any considerable thickness of strata was removed at this time, no remnants of them have been recognized. It is probable that the land was not uplifted much above the base level of the streams which drained its surface.

The Richmond submergence.—With the return of the sea in the Richmond epoch the processes of deposition were resumed under conditions similar to those which obtained during the Trenton epoch. The seas remained clear until the end of the Ordovician record. As in the case of the Upper Cambrian formations, the Bighorn and Fish Haven dolomites present no evidence, aside from the sandstone locally found at the base of the Bighorn, of proximity to shore lines. The original extent of the Bighorn formation was probably much greater than the area in which it now is found. The long period of emergence which followed its deposition afforded ample opportunity for erosion.

SILURIAN

Emergence.—During the early part of the Silurian period (Medina and Clinton epochs) the entire central Rocky Mountain region was above sea. The emergence, like the two or three next preceding ones, was accomplished, so far as the known record shows, without crustal deformation. In Wyoming, Montana, and Colorado, this interval of emergence may have continued without interruption until Devonian time.

The Niagaran(?) invasion.—Toward the middle of the period, probably in the Niagaran epoch, the sea invaded this region again, from the Great Basin side. The sediments deposited in this sea are known only in northern Utah (and in Nevada?), but may once have been far more extensive (see Fig. 10). The *Conchidium knighti* fauna found in the Laketown dolomite implies a marine connection with Alaska and with Europe.

DEVONIAN

Pre-Jefferson erosion.—The Jefferson dolomite overlaps far beyond the Laketown dolomite into western Wyoming and southwestern Montana. In Wyoming it rests upon various horizons of the Upper Bighorn dolomite. In Montana, north and west of Livingston, it lies directly upon the Upper Cambrian. It is probable that the Bighorn dolomite once extended farther into Montana, and was removed by pre-Jefferson erosion. If the Silurian system originally extended into Wyoming or Montana, it also must have been removed at this time. In Utah, no evidence of a hiatus between the Silurian and the Devonian has been noted.

Although the Jefferson dolomite overlaps both the Silurian and the Ordovician systems, the surface upon which the first sediments of the Jefferson dolomite were deposited appears to have been almost as level as that on which the Lower Bighorn dolomite was laid down. A suggestion of relief is furnished by the contrast between the sections at Logan and Livingston, Montana. Near Logan, the Jefferson rests upon Member 3 of the Cambrian system. At Livingston Peak, about 50 miles to the east, 438 feet of Bighorn dolomite intervene between the Jefferson and that member. Even this difference indicates but an inappreciable slope.

Devonian marine invasions.—The Devonian submergence, during which the Jefferson dolomite was deposited, was probably interrupted in Wyoming and Montana by at least one interval of emergence. The sea appears to have made two or three successive advances from Nevada northeastward, so that the thickness of its deposits diminishes toward the northeast because of both a progressively shorter total duration of sedimentation in that direction and, correspondingly, a progressively longer duration of the intervening emergences, with accompanying erosion. A small amount of sand, diminishing toward the northeast, was deposited in the shoreward portion of the sea during each advance. Aside from this, little or no clastic material was laid down in the Devonian sea in the central Rocky Mountain region until the later part of the period.

The Upper Devonian muds.—In the Upper Devonian the calcareous sediments accumulating on the sea bottom in Utah, Wyoming, and Montana (see Fig. 12) were polluted by an influx of mud, which in Utah attained a thickness of several hundred feet. The Three Forks formation comprises the resulting shales and limestones, together with a small thickness of arenaceous sediments, only locally present, which may date from the beginning of the Mississippian submergence rather than from the close of the Devonian. The sea which occupied parts of Colorado and central Utah in Upper Devonian time seems to have been connected directly with the Three Forks sea for a short time only, near the middle of the epoch.

THE PRE-MISSISSIPPIAN INTERVAL OF EMERGENCE

Depth of erosion.—It is certain that all of Wyoming, most of Montana, and much of Colorado was above sea-level and undergoing erosion at the close of the Devonian period. The Lower Mississippian sediments (Madison limestone) overlap all older Paleozoic formations (see Fig. 13). The gradual truncation of the Bighorn dolomite and the upper part of the Deadwood formation by the Madison limestone in the southern part of the Bighorn Range is clearly due to pre-Mississippian erosion, and the varying thickness of the Three Forks formation in northwestern Wyoming and part of southwestern Montana is due to the same cause. The relief of the final surface on which the Madison limestone rests, however, is nowhere very pronounced.

Where the Mississippian strata rest upon Ordovician rocks a part of the hiatus may be attributed to erosion during Silurian and early Devonian time; and where they lie on the Cambrian, the pre-Bighorn emergence also must be reckoned with. Again, it is probable that parts of the region never were covered by strata of the

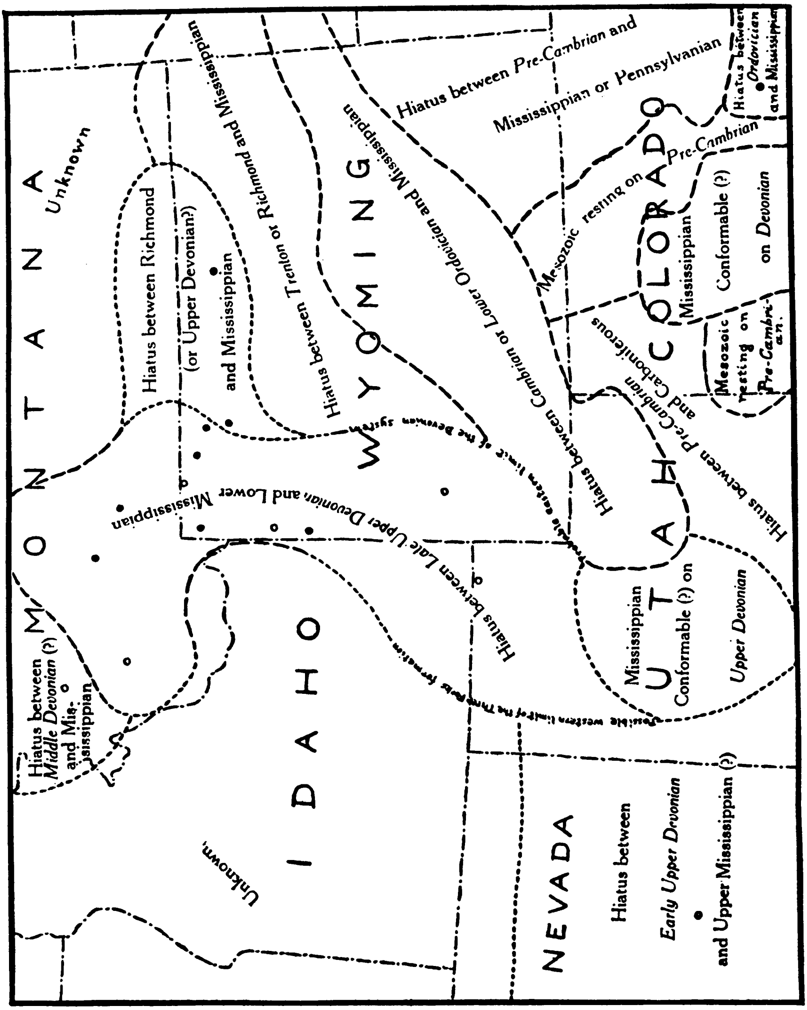
MONTANA
Unknown
Hiatus between Richmond (or Upper Devonian?) and Mississippian
Hiatus between Trenton or Richmond and Mississippian
WYOMING
Hiatus between Pre-Cambrian and Mississippian or Pennsylvanian
Hiatus between Ordovician and Mississippian
Pre-Cambrian
Mesozoic resting on Pre-Cambrian
COLORADO
Mississippian Conformable (?) on Devonian
Mesozoic resting on Pre-Cambrian
Hiatus between Cambrian or Lower Ordovician and Mississippian
Hiatus between Pre-Cambrian and Carboniferous
Hiatus between Late Upper Devonian and Lower Mississippian
UTAH
Mississippian Conformable (?) on Upper Devonian
IDAHO
Unknown
Hiatus between Middle Devonian (?) and Mississippian
NEVADA
Hiatus between Early Upper Devonian and Upper Mississippian (?)

FIG. 13.—Map showing the length of the pre-Mississippian hiatus in the central Rocky Mountain region

age of some of the formations which appear elsewhere. The extreme view, that none of the existing Middle Paleozoic formations ever extended much beyond their present limits, is certainly not true in the central Rocky Mountain region. The other extreme, that every one of them once extended over the whole area and was cut back by erosion before the Mississippian period, is likewise, in all probability, incorrect.

"Positive" and "Negative" areas; axes of warping.—Whatever was the true proportion between erosion and non-deposition, the net result is shown in Fig. 13, which is, in effect, a paleo*geologic* map of the central Rocky Mountain region at the close of the pre-Mississippian interval of emergence. If the area of Cambrian and pre-Cambrian rocks which then extended from eastern Utah northeastward across southern Wyoming and northern Colorado owed its exposure to the erosion of Middle Paleozoic formations during emergent intervals, it certainly was more exposed to erosion during those intervals than were the adjacent areas on either side of it—probably because of greater altitude. If its exposure was due wholly to non-deposition of the Middle Paleozoic formations, then it must have been above water when neighboring areas were submerged. In either case, or under any hypothesis which combines the two views, *this area of Cambrian and pre-Cambrian rocks must have been at a greater average altitude* during Middle Paleozoic time than the areas on either side of it.

The major axis of this area of upward tendency is approximately at right angles to the average trend of the Rocky Mountain folds. The downward-tending belt, which is known to have been covered by most of the Middle Paleozoic seas, extends in parallel fashion from the northern part of the Great Basin northeastward across the Rocky Mountain province. This is well illustrated by the distribution of the Bighorn dolomite (see Fig. 9).

The trend of these belts indicates the direction of axes of warping merely, not of true orogeny.

The pre-Mississippian interval of emergence was brought to a close by an invasion of the sea, whose deposits are more widespread in the central Rocky Mountain region than are those of any preceding submergence.